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Soil Erosion from Tillage and Planting Systems Used in Soybean Residue: Part II - Influences of Row Direction

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ABSTRACT

A rainfall simulator was used to compare soil losses from tillage and planting systems used in residue from soybeans. The study was conducted on a silty clay loam soil in the Wymore Series with a 5% slope and on a silt loam soil in the Nora Series with a 10% slope. Tillage and planting treatments, ranging from a moldboard plow system to no-till planting, were evaluated both up-and-down hill and on the contour using replicated plots.

For the first rainfall event after tillage and planting, the average soil loss for all systems on the contour was 3.0 t/ha which was a 74% reduction from the average soil loss of 11.5 t/ha for tillage and planting conducted up-and-down hill. Similarly, the average soil erosion rate for systems on the contour was 9.5 t/(ha·h), a 65% reduction from the 26.2 t/(ha·h) average soil erosion rate for up-and-down hill tillage systems. All tillage systems compared showed a significant reduction in soil erosion, soil erosion rate, and sediment concentration for row direction on the contour rather than with the slope.

INTRODUCTION

The use of crop residue to reduce soil erosion has been documented by many researchers. Other conservation practices can also be used to reduce soil losses. For example, Schwab et al. (1966) stated that the adjustment of tillage and crop management from up-and-down hill to contour operations is one of the basic engineering practices in conservation farming. They discussed studies where contouring reduced soil erosion by 60% or more, and one study where soil losses from soybeans on the contour were approximately 75% less than losses from noncontoured areas. The Universal Soil Loss Equation places the erosion reducing effects of contouring (P factor) at 10 to 50% (Wischmeier and Smith, 1978).

A study was undertaken to evaluate the influences of soybean residue grown in wide rows and used in concert with contouring on soil erosion during the period between spring planting and crop canopy establishment for selected tillage and planting systems. Specific objectives were to measure and compare soil surface cover, soil erosion, water runoff, and sediment concentration in the runoff for tillage and planting systems used up-and-down hill and on the contour (Part II). A concurrent study (Part I) compared tillage and planting systems used up-and-down hill in soybean residue which had been grown in both narrow and wide spaced rows (Shelton et al., 1986).

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METHODOLOGY

Research, using simulated rainfall, was conducted at two locations in order to obtain soil erosion information from different soil series and slopes. One location was at the University of Nebraska Rogers Memorial Farm in Lancaster County, near Lincoln, NE. The silty clay loam soil at this site was within the Wymore Series (Aquic Argiudoll, fine, montmorillonitic, mesic) on a 5% slope (SCS, 1980). The other site was at the University of Nebraska Northeast Research and Extension Center in Dixon County, near Concord, NE. The silt loam soil at this location was in the Nora Series (Udic Haplustoll, fine-silty, mixed, mesic) on a 10% slope (SCS, 1978).

The primary treatment comparison was between residue from soybeans in wide spaced rows running up-and-down hill and residue from soybeans that had been planted on the contour in wide spaced rows. A completely randomized experimental design was used at each location to compare the two treatments for a variety of tillage and planting systems. Within location, the same soybean variety and planting population were used in 76 cm spaced rows to produce residue for both the contour and up-and-down hill treatments. To obtain similar initial conditions prior to planting soybeans in 1982, all plot areas at the Rogers Memorial Farm were disked twice and planted with Williams variety soybeans at approximately 353,000 seeds/ha. Initial experimental conditions at the Northeast Center were given by Shelton et al. (1986). Soybean grain yield averaged 1,890 kg/ha at the Rogers Farm on the silty clay loam soil while the yield at the Northeast Center on the silt loam soil averaged 2,390 kg/ha.

Five tillage and planting systems were evaluated in the soybean residue, with the tillage and planting direction matching the previous year's row direction. Individual tillage plots were positioned to obtain nearly equivalent slopes. Because of field layout, the up-and-down hill tillage system treatments were replicated three times, while the contour treatments were replicated four times. All field operations were performed in the spring of 1983. Specific field operations, in order, within each system are listed in Table 1. On the silty clay loam soil at the Rogers

TABLE 1.
SUMMARY OF TILLAGE AND PLANTING SYSTEMS EVALUATED AT THE TWO LOCATIONS.

Tillage and planting system — operations	Location
Moldboard plow — moldboard plow (20 cm deep), disk (15 cm deep), disk (10 cm deep), plant	N,R*
Double disk — disk (15 cm deep), disk (10 cm deep), plant	N
Disk — disk (15 cm deep), plant	R
Strip rotary-till — rotary-till (13 cm deep; 25 cm wide) on old row, plant	N
No-till — slot-plant into old row	N,R

*N = Northeast Center, silt loam soil, 10% slope
R = Rogers Farm, silty clay loam soil, 5% slope

Farm, a model 800 International Harvester* six-row planter (76 cm spacing) with rippled coulters was used. Rainfall simulations were on June 2-3, 1983 at this location. Details of tillage and planting implements used on the silt loam soil at the Northeast Center, as well as a description of the rainfall simulator and other experimental procedures have been given by Shelton et al. (1986). At both locations the rainfall applied with the simulator was the first rainfall event after the planting operation.

Duncan's Multiple Range Test was employed for the statistical analyses, with the ten percent level (P=0.10) used to determine significant differences.

*Mention of brand names is for descriptive purposes only, endorsement is not implied.

RESULTS AND DISCUSSION

Soil Surface Cover

Residue cover ranged from 1.7 to 48.4% for the tillage and planting systems evaluated (Table 2). There tended to be less residue cover for systems on the contour, although the disk system used on the silty clay loam soil did have significantly more cover when used on the contour compared to the up-and-down hill direction. The no-till planting treatments had significantly more residue cover than the other systems which had residue covers well below the 30% requirement for conservation tillage (CTIC, 1984).

Soil Erosion

Cumulative soil losses from the tillage treatments used up-and-down hill and on the contour are shown in Fig. 1. The results tended to be separated into two groups with less soil loss occurring from systems on the contour. No-till planting on the contour had the least soil loss of any system.

Each system on the contour exhibited a significant reduction in soil loss after 50 mm of water application when compared to the same system conducted up-and-down hill (Table 2). The average soil loss reduction for contouring was 74% at each site. This result closely paralleled research by Dickey et al. (1983) which showed that moldboard plowing on the contour reduced soil erosion by 77% in a wheat-fallow rotation, compared to plowing up-and-down hill.

No-till planting reduced soil losses at both sites. Compared to the double disk system, no-till planting on the silt loam soil significantly reduced soil losses by 49 and 73% for the up-and-down hill and contour treatments, respectively (Table 2). On the silty clay loam soil, for up-and-down hill row direction, no-till planting

TABLE 2.
MEASURED SURFACE RESIDUE COVER, SOIL LOSS, AND SOIL EROSION RATE FOR TILLAGE AND PLANTING SYSTEMS USED IN RESIDUE FROM SOYBEANS THAT HAD BEEN GROWN BOTH UP-AND-DOWN HILL AND ON THE CONTOUR IN WIDE (76 cm) SPACED ROWS.

	Residue cover,† %			Soil loss,‡ t/ha			Soil erosion rate,§ t/(ha·h)		
Tillage and planting system	Up-and-down hill		Contour	Up-and-down hill		Contour	Up-and-down hill		Contour
Northeast Center, 10% slope, silt loam soil									
Moldboard plow	2.0^{a}		1.7^{a}	13.0^{a}	*	2.2^{ab}	37.4^{a}	*	12.9^{a}
Double disk	10.6^{a}		7.2^{b}	10.1^{ab}	*	4.4^{a}	27.8^{b}	*	14.5^{a}
Strip rotary-till	11.6^{a}		11.4^{c}	7.8^{bc}	*	1.7^{b}	22.3^{b}	*	6.9^{b}
No-till	48.4^{b}		36.8^{d}	5.1^{c}	*	1.2^{b}	13.1^{c}	*	3.3^{b}
Rogers Farm, 5% slope, silty clay loam									
Moldboard plow	3.0^{a}		2.2^{a}	14.9^{ab}	*	4.7^{a}	32.1^{a}	*	14.4^{a}
Disk	11.5^{b}	*	15.4^{b}	20.8^{a}	*	4.8^{a}	35.5^{a}	*	10.8^{a}
No-till	41.0^{c}	*	32.5^{c}	8.8^{b}	*	2.2^{a}	15.5^{b}	*	3.7^{b}

*A significant difference exists between up-and-down hill and contour for these tillage treatments only (Duncan's Multiple Range Test, 10% level of significance).
†Residue cover measurements taken after tillage and planting, but prior to rainfall simulation.
‡Total accumulated soil loss after 50 mm of water application.
§Soil erosion rate after reaching equilibrium conditions between water application and water runoff.
a,b,c Values within each column, within location, having the same superscript are not significantly different (Duncan's Multiple Range Test, 10% level of significance).

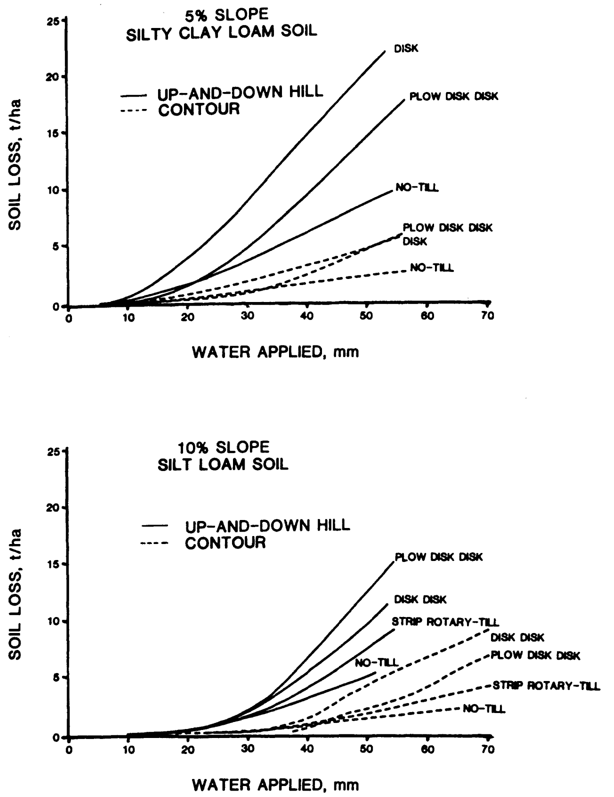

Fig. 1—Cumulative soil loss vs. water application for different tillage and planting treatments used up-and-down hill and on the contour in residue from wide row soybeans.

also significantly reduced soil losses by 58% compared to the single disk system.

Soil losses tended to be greater from the disk treatments than from the moldboard plow treatments. One possible reason for this trend may be that a moldboard plow buries some of the mellow surface soil left by soybeans, whereas a disk primarily loosens the already mellow surface, thus making the soil more vulnerable to erosion.

Equilibrium Soil Erosion Rate

Equilibrium soil erosion rate, or the rate of soil loss after equilibrium had been established between water runoff and water application, was significantly reduced for all systems on the contour compared to systems used up-and-down hill (Table 2). The average reduction was approximately 65% for both soils. The moldboard plow system, used up-and-down hill on the silt loam soil had a significantly greater rate of soil loss, 37.4 t/(ha·h), than the erosion rates from the other three systems. No-till planting significantly reduced soil erosion rates by as much as 77% compared to tillage systems using a disk for both soil types and row directions.

Soil Erosion Rate and Surface Cover

The data on crop residue cover and equilibrium soil erosion rate at each site for each row direction were analyzed to fit the exponential equation,

$$\text{Equilibrium Erosion Rate} = Ae^{B \cdot RC} \quad \ldots\ldots\ldots\ldots [1]$$

where A and B are regression coefficients and RC is the percent surface cover. Equilibrium erosion rates, rather than cumulative soil losses were used to develop these relationships in order to equalize some of the differences in runoff start times between the up-and-down hill and contour treatments.

The values of B ranged between −0.018 and −0.039 (Table 3), and were near the upper end of the range of −0.03 to −0.07 reported for row cropped land for soil loss versus residue cover relationships (Laflen et al., 1980; Laflen and Colvin, 1981; and Dickey et al., 1984 and 1985). These B coefficients indicated more sensitivity in erosion rate to changes in residue cover for contour planting than for up-and-down hill planting for both soils.

TABLE 3. REGRESSION AND CORRELATION COEFFICIENTS FOR THE GENERALIZED EQUATION EQUILIBRIUM EROSION RATE IN t/(ha·h) = $Ae^{B \cdot RC}$; WHERE RC IS THE PERCENT SURFACE COVER.

	Regression coefficients		
Row direction	A	B	Correlation coefficient
Northeast Center, 10% slope, silt loam soil			
Up-and-down hill	34.7	−0.023	0.78
Contour	14.6	−0.039	0.67
Rogers Farm, 5% slope, silty clay loam soil			
Up-and-down hill	37.3	−0.018	0.71
Contour	16.0	−0.035	0.68

The projected equilibrium soil erosion rates (A values) were similar for the two soils for the same planting direction (Table 3). Predicted soil erosion rates for cleanly tilled or residue free conditions were reduced by more than 57% by planting on the contour, rather than up-and-down hill.

Projected equilibrium soil erosion rates were nearly 70% less when a 20% residue cover was left on the contour, rather than up-and-down hill. Further, leaving a 20% cover of soybean residue and planting on the contour would reduce the soil erosion rate for the silt loam soil by 28.0 t/(ha·h), or 81%, compared to cleanly tilled, up-and-down hill conditions. Averaged across row direction and soil type, the predicted soil erosion rate would be 43% lower with a 20% residue cover than for residue free conditions. This is similar to the 50% reduction in soil erosion reported by Dickey et al., (1984, 1985) and a 42% reduction in soil erosion calculated from information reported by Shelton et al. (1986).

Runoff

Tillage and planting treatments on the contour were very effective in delaying the start of runoff (Table 4). All but one system used on the contour had a significant increase in the time beteen the start of water application and runoff, when compared to the up-and-down hill treatments.

There was a trend toward less total accumulated runoff after 50 mm of water application for tillage systems on the contour (Table 4) with the greatest reduction being 79% for the moldboard plow system on the silt loam soil. However, only one system at each site showed a significant reduction for contour compared to up-and-down hill operations.

The water runoff rate was about 10% less from tillage

TABLE 4. MEASURED WATER RUNOFF START TIMES, ACCUMULATED WATER RUNOFF, RUNOFF RATE, AND AVERAGE SEDIMENT CONCENTRATION IN THE RUNOFF WATER FOR TILLAGE AND PLANTING SYSTEMS USED IN RESIDUE FROM SOYBEANS THAT HAD BEEN GROWN BOTH UP-AND-DOWN HILL AND ON THE CONTOUR IN WIDE (76 cm) SPACED ROWS.

	Start of runoff,† min.			Accumulated runoff,‡ mm			Runoff rate,§ mm/h			Sediment concentration,‖ ppm		
Tillage and planting system	Up-and-down hill		Contour	Up-and-down hill		Contour	Up-and-down hill		Contour	Up-and-down hill		Contour
										(x1000)		
Northeast Center, 10% slope, silt loam soil												
Moldboard plow	12.3^{a}	*	40.8^{a}	11.7^{a}	*	2.5^{b}	33.3^{a}		36.6^{ab}	111.2^{a}	*	59.0^{a}
Double disk	11.0^{a}	*	28.8^{b}	11.9^{a}		8.6^{a}	34.3^{a}		43.4^{a}	90.0^{ab}	*	50.0^{ab}
Strip rotary-till	13.0^{a}	*	27.3^{b}	10.9^{a}		8.1^{a}	30.0^{a}	*	43.2^{a}	71.4^{b}	*	23.7^{bc}
No-till	10.7^{a}	*	20.3^{b}	12.4^{a}		6.6^{ab}	30.5^{a}		30.0^{b}	41.5^{c}	*	17.4^{c}
Rogers Farm, 5% slope, silty clay loam soil												
Moldboard plow	8.3^{a}		9.5^{a}	21.3^{b}		17.5^{b}	53.8^{a}		51.8^{a}	71.6^{a}	*	25.1^{a}
Disk	5.0^{b}	*	8.0^{a}	32.0^{a}		25.1^{a}	55.4^{a}		49.0^{a}	64.3^{ab}	*	17.3^{ab}
No-till	5.7^{b}	*	10.5^{a}	27.2^{a}	*	17.5^{b}	49.0^{a}	*	38.4^{b}	33.8^{b}	*	12.7^{b}

*A significant difference exists between up-and-down hill and contour for these tillage treatments only (Duncan's Multiple Range Test, 10% level of significance).
†Minutes of elapsed time from start of water application until runoff occurred.
‡Total accumulated water runoff after 50 mm of water application.
§Water runoff rate after reaching equilibrium conditions between water application and water runoff.
‖Sediment concentrations were determined by dividing the total accumulated soil loss by the total accumulated water runoff after 50 mm of water application.
a,b,cValues within each column, within location, having the same superscript are not significantly different (Duncan's Multiple Range Test, 10% level of significance).

systems used on the contour on the silty clay loam soil as compared to systems used up-and-down hill (Table 4), although the difference was significant only for the no-till system. An opposite trend occurred for the silt loam soil where there was an increase of 20% in the average runoff rate for the treatments on the contour compared to up-and-down hill rows. However, only the strip rotary-till system had a significant increase.

In their discussion of contouring, Wischmeier and Smith (1978) state that "the practice provided almost complete protection against erosion from storms of moderate to low intensity, but it provided little or no protection against the occasional severe storms that caused extensive break-overs of the contoured rows." This phenomenon was particularly evident for the silt loam soil. At this site, the wheel tracks and ridges left by the planter were especially pronounced, and rainfall simulation was conducted almost immediately after planting, before naturally occurring rainfall and runoff had established a drainage network. These intact ridges allowed substantial amounts of water to be applied before runoff occurred. Approximately 12 mm of water was applied to the up-and-down hill treatments before runoff occurred, whereas an average of 43 mm of water was applied to the moldboard plow treatment on the contour before runoff started.

Part of the water applied prior to the initiation of runoff was trapped upslope by the intact ridges left by the planter. As additional water was applied, the ridges were overtopped, and the establishment of a drainage network initiated. However, the ponded water may have contributed to some sealing of and/or sedimentation on the soil surface. This would have reduced the infiltration rate, thereby increasing the equilibrium runoff rates. Even though the average runoff rate tended to be greater, soil erosion rates were significantly reduced for all systems on the contour compared to up-and-down hill systems (Table 2). Ponded water remaining behind the ridges may have reduced the surface area exposed to direct raindrop impact, thus reducing the amount of splash erosion and hence the amount of soil detachment.

This study evaluated the influece of contouring only for the first rainfall event after tillage and planting. A significant benefit of contouring was demonstrated by reducing the cumulative soil loss and soil erosion rate, and delaying the time for runoff to begin. Accumulated runoff after 50 mm of water application was also reduced, but the equilibrium runoff rate increased. It is likely that the benefits of contouring would not be quite as pronounced for subsequent rainfall events since a drainage network would have been established and soil sealing and/or crusting from previous rainfall would have existed in all treatments.

Sediment Concentration

Sediment concentrations in the runoff water during rainfall simulation were significantly reduced for all tillage and planting systems on the contour as compared to systems conducted up-and-down hill (Table 4). This reduction averaged 41,000 ppm or 52% for the silt loam soil, and 68% or 38,200 ppm for the silty clay loam soil.

Sediment concentration in the runoff water versus water applied is illustrated in Fig. 2. After runoff reached equilibrium, the moldboard plow system used up-and-down hill on the silty clay loam soil had the greatest concentration of sediment in the runoff water, while the no-till treatment on the contour had the least. The curves fell into two groups, with the moldboard plow

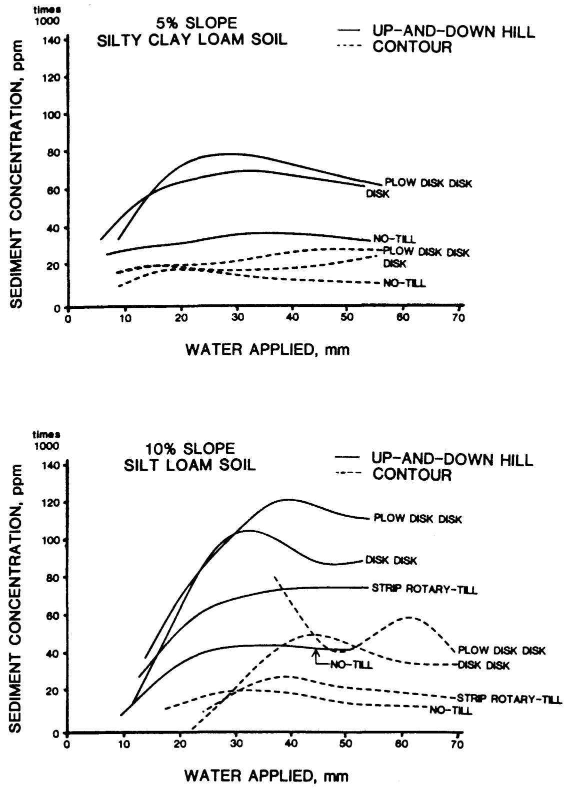

Fig. 2—Sediment concentration in the runoff water vs. water application for different tillage and planting treatments used up-and-down hill and on the contour in residue from wide row soybeans.

and disk systems used up-and-down hill forming one group, and all other treatments clustered into a second group having reduced sediment concentrations.

The sediment concentration curve (Fig. 2) for the moldboard plow system used on the contour on the silt loam soil further illustrates the effects of wheel tracks, planter ridges, and drainage network establishment. Runoff did not start from any of the four individual tillage plots until approximately 35 mm of water had been applied. At this point, some ridges broke, and the runoff water had a large sediment load, hence the large sediment concentration at the start of the curve. After this initial break-over, ponded water would have been released through the initial channels at a relatively constant rate. As more water was applied, runoff continued, with another series of break-overs or washouts occurring, which gave a peak to the sediment concentration curve at about 60 mm of applied water. After this point, runoff continued at a relatively constant rate, which was greater than the rate following the initial breakover. Again, had a subsequent simulation been performed, sediment concentrations may have been more uniform since much of the drainage network would have been established.

Drainage Network Effects

The previous results and discussions of soil loss, water runoff, and sediment concentration (Tables 2 and 4) were after a total of 50 mm of water had been applied. This may have biased the results somewhat in favor of the contour treatments, since a drainage network may not have been fully established at this time. In order to equalize some of the effects of drainage network

TABLE 5. MEASURED SOIL LOSS, ACCUMULATED WATER RUNOFF, AND AVERAGE SEDIMENT CONCENTRATION IN THE RUNOFF WATER 45 MIN AFTER RUNOFF HAD BEGUN FOR TILLAGE SYSTEMS USED IN RESIDUE FROM SOYBEANS THAT HAD BEEN GROWN BOTH UP-AND-DOWN HILL AND ON THE CONTOUR IN WIDE (76 cm) SPACED ROWS.

Tillage and planting system	Soil loss,† t/ha: Up-and-down hill		Soil loss,† t/ha: Contour	Accumulated runoff,‡ mm: Up-and-down hill		Accumulated runoff,‡ mm: Contour	Sediment concentration,§ ppm: Up-and-down hill		Sediment concentration,§ ppm: Contour
							(x 1000)		
Northeast Center, 10% slope, silt loam soil									
Moldboard plow	19.2^{a}	*	10.6^{a}	23.4^{a}		17.3^{a}	111.8^{a}	*	44.2^{a}
Double disk	14.4^{b}		10.7^{a}	17.0^{a}	*	26.9^{a}	88.9^{ab}	*	39.1^{a}
Strip rotary-till	11.8^{b}	*	4.6^{b}	16.3^{a}	*	25.1^{a}	72.6^{b}	*	18.4^{b}
No-till	7.0^{c}	*	2.1^{b}	16.5^{a}		15.5^{b}	42.4^{c}	*	14.0^{b}
Rogers Farm, 5% slope, silty clay loam soil									
Moldboard plow	18.2^{ab}	*	6.3^{a}	27.2^{b}		23.9^{ab}	69.7^{a}	*	25.5^{a}
Disk	22.6^{a}	*	5.8^{a}	35.1^{a}		30.0^{a}	63.8^{a}	*	18.2^{ab}
No-till	9.8^{b}	*	2.6^{a}	30.2^{ab}	*	22.9^{b}	33.6^{b}	*	11.9^{b}

*A significant difference exists between up-and-down hill and contour for these tillage treatments only (Duncan's Multiple Range Test, 10% level of significance).

†Total accumulated soil loss 45 min after the initiation of runoff.

‡Total accumulated water runoff 45 min after the initiation of runoff.

§Sediment concentrations were determined by dividing the total accumulated soil loss by the total accumulated water runoff 45 min after the initiation of runoff.

a,b,c Values within each column, within location, having the same superscript are not significantly different (Duncan's Multiple Range Test, 10% level of significance).

establishment, analyses of these parameters were also conducted 45 min after runoff had begun (Table 5).

With only one exception, systems on the contour showed a significant reduction in soil loss 45 min after runoff had begun. However, the average soil loss for the treatments on the contour for the silt loam soil was reduced by only 47% compared to up-and-down hill rows, as contrasted to a 74% reduction after 50 mm of water application. There was a significant difference in soil loss 45 min after runoff had begun between the no-till and moldboard plow systems on the contour for the silt loam soil unlike the non-significant difference that occurred after 50 mm of water application.

Averaged across tillage systems and locations, systems on the contour and up-and-down hill had approximately the same amount of accumulated runoff water 45 min after runoff had begun, whereas systems on the contour had averaged 32% less water runoff after 50 mm of water application as compared to systems conducted up-and-down hill. Further, after runoff had occurred for 45 min, all tillage treatments showed a decrease in the percentage of water retained compared to the percentage of water retained after 50 mm of water application.

Similar to the trend after 50 mm of water application, sediment concentrations were significantly lower for treatments on the contour compared to up-and-down hill treatments 45 min after runoff had begun (Table 5). The sediment concentrations after 45 min of water runoff tended to be similar to, or less than the concentrations after 50 mm of water application. This may further reflect the effects of ponding and the establishment of a drainage network in the contour treatments, as the ponded water may have drained through established channels and may have been relatively free of sediment, thus giving a decreased sediment concentration in the runoff water.

SUMMARY AND CONCLUSIONS

Soil erosion from selected tillage and planting systems used on the contour and up-and-down hill in soybean residue were evaluated using a rotating boom rainfall simulator. The tillage systems were used on a silty clay loam soil in the Wymore Series with a 5% slope and a silt loam soil in the Nora Series having a 10% slope.

Soil losses were reduced by 74% and soil erosion rate by approximately 65% for planting on the contour as compared to up-and-down hill planting. As drainage networks were established, the differences between erosion from the contour and up-and-down hill plots became less.

For tillage and planting systems used on the contour, the time required to initiate runoff was significantly longer than for comparable systems used up-and-down hill. Water runoff from treatments on the contour was reduced by an average of 45% on the 10% slope, and 25% on a silty clay loam soil with a 5% slope compared to up-and-down hill treatments. Runoff rate increased by 20% for contouring on the 10% slope, but decreased 12% on the 5% slope. Differences in runoff and runoff rate between systems on the contour compared to up-and-down hill tillage and planting were generally non-significant.

No-till planting, without exception, left the most residue on the soil surface and had the least soil loss, about 60% less than the treatments involving a disk as the primary tillage implement. There tended to be less soil erosion from the moldboard plow system than from the disk systems because the plow tends to bury the mellow soil created by soybean production. In soybean residue, a disk represents a poor choice of tillage implement when considering the erosion potential.

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